USE OF COMPUTER-ASSISTED MATCHING OF PHOTOGRAPHS TO EXAMINE POPULATION PARAMETERS OF ALASKAN HARBOR SEALS

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INTRODUCTION

Trends in the number of harbor seals hauled-out during the annual molting period have been estimated for representative areas throughout the range of this species in Alaska (Small *et al.* 2001, Small 1998, Frost *et al.* 1999). However, these trends do not provide an understanding of the underlying changes in survival, reproduction, or movement and haulout patterns of seals needed for effective conservation and management. In general, pinniped population abundance is much more sensitive to changes in survival than reproduction (Eberhardt and Siniff 1977). Population modeling has demonstrated that population dynamics of both Steller sea lions (York 1994) and harbor seals (Frost *et al.* 1996) in Alaska are sensitive to changes in juvenile survival. Therefore, understanding survival patterns is particularly critical to conservation of Alaskan harbor seals.

Mark-recapture techniques provide a powerful method for estimating these demographic parameters (Seber 1982). In traditional mark-recapture studies, individual animals are captured and 'marked' with a unique identifier (e.g., brand or tag), and then either recaptured or resighted at later periods. Such studies have not been attempted on harbor seals in Alaska, primarily due to the difficulty in capturing and resighting the large number of animals required for precise estimates of survival. Additionally, there are few haulouts in Alaska where researchers can get close enough to seals to resight marks.

In this chapter we describe an alternative method of marking individual harbor seals through the use of photo-identification (photo-id). Photo-id has been successfully used to identify individuals in several marine mammal species, including Florida manatees (*Trichechus manatus latirostris*; Langtimm *et al.* 1998), Mediterranean monk seals (*Monachus monachus*; Forcada and Aguilar 2000), New Zealand sea lions (*Phocarctos hookeri*; McConkey 1999) and many cetacean species, most notably, humpback whales (*Megaptera novaeangliae*; Mizroch *et al.* 1990). These studies used manual categorization of fluke shape (in cetaceans), or scars and natural markings, to match individuals in photographs. The use of photo-id to identify individual harbor seals over several years by their natural markings has been used successfully for small populations in British Columbia (Olesiuk *et al.* 1996) and for populations in California (Yochem *et al*. 1990) and Alaska (Crowley *et al.* 2001). Hiby and Lovell (1990) developed an objective photograph matching technique that used a three-dimensional computer model to recognize natural-marking patterns of grey seals (*Halichoerus grypus*). This technique has been used to match and catalog over 6,000 individuals (Hiby and Lovell 1997). Beginning in 1998, we attempted to use the method of Hiby and Lovell (1990) to objectively match photographs of harbor seals from Tugidak Island, Alaska.

The success of a long-term program to examine demographic parameters of harbor seals using photo-id depends on the consistency of the pelage patterns over the lifespan of individuals, the accuracy and efficiency of matching photographs, and the ability to obtain representative and large samples to ensure adequate resighting rates. Short-term studies found pelage patterns of individuals were consistent over at least several years in adult (Olesiuk *et al.* 1996, Yochem *et al.* 1990) and young harbor seals (Kelly 1981). Long-term age-related changes in pelage patterns are currently being tested by photographing over a series of years known-age captive seals at aquariums, and seals tagged as pups and scarred animals on Tugidak Island. These data will be analyzed after several more years of data collection. Data collected since 1998 on Tugidak Island allow preliminary evaluations of the photograph matching technique and potential resighting rates of Tugidak seals using photo-id. Sufficiently high resighting rates are needed to precisely estimate population parameters using mark-recapture models and to ensure representative samples of the population (Pollock *et al.* 1990). In this chapter, we (1) summarize data collected to date, (2) evaluate the performance of the Hiby and Lovell (1990) method in matching photographs of harbor seals, and (3) present preliminary estimates of resighting rates in order to evaluate the applicability of using photo-id to monitor demographic parameters of harbor seals at a large haulout.

METHODS

Data collection

Seals were photographed from a cliff, 20 to 40 meters above two main haulouts (Southwest Beach and Middle Beach) on Tugidak Island, Alaska (56° 30’ N, 154° 40’ W). A Nikon F3 35 mm camera with Celestron C8 telescopic lens (2032 mm, ~40x) and Ilford XP2 400 ASA black and white film were used to photograph seals. Photographs were generally taken between 0900 and 1500 hours on days when winds were less than 12 knots, during the pupping (May-June) and molting (August-September) seasons in 1998 and 1999. All seals that were fully molted on the head and showing a view of the head were photographed. Seals were photographed regardless of the extent of pelage marking on the head. Multiple (usually two to five) photographs of the same seal were taken from all visible sides of the head (left, right or front views). While photographing, a temporary animal number was assigned to each seal. We also recorded molt stage (Jemison *et al.* 1998), age-class, sex (if the seal showed its’ ventrum), color phase (light, intermediate, and dark; see Kelly 1981 for explanation of color phase) and whether the pelage on the head was wet or dry.

Photograph matching technique

Conservation Research Ltd. developed a three-dimensional model of a harbor seal head to correct for viewpoint and posture and determined three “fingerprint” regions, one each for the left, right, and front views of the head (Figure 1). Initial subjective screening excluded negatives of very poor quality (e.g., unfocused photographs, photographs of extremely angled heads; 6.4% of photos). The remaining negatives were digitized and all “temporary” seals with digitized negatives were manually assigned permanent animal numbers. For these seals, one to two of the best photographs were selected for “fingerprinting”. Fingerprinting involved first fitting the three-dimensional head model to the image of the head on the photograph. The fingerprint region was then isolated from the image and the grey-scale intensities were evaluated for each coordinate in the region by the software program developed by Conservation Research Ltd. The resulting numerical description of the fingerprint region is termed the “identifier array” (IA). Each fingerprint (in IA form) was then compared with all other fingerprints of the same view (left, right or front) in the database using this software. Each comparison generated a “similarity score” which was defined as the correlation coefficient between corresponding elements in the IA. The correlation was calculated for several subregions within the IA and the average of the subregions was used to reduce the influence of gradual shifts in lighting conditions (Hiby and Lovell 1990). The software also accounted for alignment errors by determining the maximum correlation coefficient by stretching and shearing one IA over the other.

After all comparisons for a particular fingerprint were complete, the similarity scores for that fingerprint were standardized by the mean score that fingerprint obtained from comparisons with all other fingerprints in the database. The standardized score was therefore expressed as the number of standard deviations the score lied above the mean score. An initial value of the standardized score that represented a match was chosen to be 1.9 (or 1.9 SD above the mean score), the critical value chosen previously for matching grey seal photos after extensive experience with the software. All matches that generated standardized scores above this critical level were compared by eye to confirm the match and update the permanent animal number (for a full explanation of the matching process and software see Hiby and Lovell, 1990). By confirming all matches by eye the probability of a false positive match is essentially zero. The probability of a false negative (a missed match) must be assessed by other means.

Performance of matching technique

False negatives erroneously assign multiple permanent animal numbers to a single seal and should be avoided. Duplicates in the database will inflate the number of new marks in the database resulting in over-estimates of abundance and biased estimates of annual survival. A preliminary evaluation of the *photograph* matching error rate was conducted using the 1998 photographs. The similarity scores for matching (having the same permanent animal number) and non-matching (having different animal numbers) fingerprints were compared for side (left and right combined) and front views. A subsequent exercise in which all 1999 pupping, 1998 pupping and 1998 molting photographs were compared by eye for matches found only one new match not found from the matching algorithm. Therefore the matching algorithm’s ability to determine the correct permanent animal number was reliable. The proportion of scores from matching fingerprints that were below 1.9 provided a rough estimate of the probability of false negatives, while the proportion of scores from non-matching fingerprints that were above 1.9 provided an evaluation of the efficiency of the process (the proportion of non-matching photographs that were checked by eye), when using a critical value of 1.9.

This procedure provided only a preliminary evaluation of the matching process and estimate of matching error rates. A true reliability test should be done using photographs where matches are identified using means other than the matching algorithm itself, for example from photographs of tagged or scarred individuals. At the time of this report, however, data from individuals with alternative marks (tags or scars) were too few to perform a more thorough reliability test.

Preliminary estimation of resighting rates

Between-year resighting rates

Estimation of annual survival probability is dependent on *between-year* resighting rates. Preliminary estimates of *between-year* resighting rates were calculated by assuming no emigration from the population and an annual survival probability of 0.80, using equation (1): $p = [r_{1999} / m_{1998}] / \phi$, where p = resighting rate estimate, r_{1999} = number of resights in 1999 of seals marked in 1998, m_{1998} = total number of seals marked by the end of 1998, and ϕ = survival probability. The beginning of equation (1), $[r_{1999} / m_{1998}]$, is often termed the return rate. Resighting rates were calculated for all seals (regardless of age) and adults and subadults only, because resighting rates of young seals may be much lower than those of older seals (Hastings and Testa 1999). Adults and subadults were grouped because they are often hard to distinguish in the field.

Resighting probability determined from photo-id data includes the probability of missing matches, and matching error rate likely depends greatly on photograph and pelage pattern quality (Hiby and Lovell 1997, Forcada and Aguilar 2000). By using all photographs regardless of photograph or pelage pattern quality, resighting rates will likely be underestimated. Although objective means of determining quality are still being developed, a preliminary exercise combining subjective and objective techniques for categorizing quality was conducted to determine an upper value for annual resighting rate. Objective categorization included all images for which less than 50% of the fingerprint region was obscured (e.g., by sand or a flipper) and for which the camera axis was between 50° behind to 80° in front of the particular view. Subjective categorization was based on clarity of pattern and was determined by one observer most experienced in using the software and working with the photographs. Because categorization by quality has been completed only for the 1999 data at this time, annual resighting rate cannot be directly estimated for seals with high-quality photos. Instead the proportion of fingerprints classified as "high-quality" was assumed equal in the 1998 and 1999 data. This proportion was then used to reduce the total new marks to give the total well-marked seals marked by the end of 1998. We did not adjust the total resights in 1999 but instead assumed all resights were of well-marked individuals. This yielded the least conservative estimate of resighting rate.

Within-season resighting rates

For estimation of some demographic parameters, such as population size (N), pup survival, and reproductive rate, sufficient *within-season* resighting rates are required. Estimation of these demographic parameters is complicated by variation in the timing of molt among individuals and age/sex-classes (Jemison *et al.* 1998, Daniel *et al.* 2001), because matching ability likely depends on molt stage. The software will likely reliably match only photographs of fully molted or nearly fully molted seals. This condition necessitates a reinterpretation of some parameters estimated by the Jolly-Seber model. For example, to estimate population size during the molting season, births into the population (B) should be interpreted as the apparent movement of individuals into the "matchable" population by completion of molt, and within-season survival rate (ϕ) as the retention rate of animals in the population (or the inverse of emigration, assuming mortality rate during the end of the molt period is negligible). Whereas the parameters B and ϕ are not of interest biologically in this case, they are necessary for estimation of population size.

To examine potential within-season resighting rates and other parameters (N, B and ϕ), we fit the Jolly-Seber and Cormack-Jolly-Seber model to data from the molt season 1999 when intensive within-season sampling was conducted. To do this, the 19 sampling days during this season were condensed to 6 capture occasions to mimic time intervals that are needed for survival estimation. Specifically, photographs taken between August 17 and September 1 were combined into capture occasion 1, because no resightings were made during this period though many new marks were acquired. The next five occasions were created by grouping 2-3 days of photographing into 6 capture occasions: Sept 4-5, Sept 6-8, Sept 11-12, Sept 13-14, and Sept 18-19. Therefore time intervals between consecutive occasions ranged from an average of 9 days (from the first to second capture occasion) to an average of 2 to 5 days for the last five capture occasions. Only data from photographs categorized as "high-quality" as described for between-year resighting rate were used in this analysis. These capture histories were analyzed using the programs JOLLY (Pollock *et al.* 1990) and MARK (White and Burnham 1999).

RESULTS

Summary of data collected

Seals were photographed on 10, 9, 12, and 19 days for the following seasons: pupping 1998, molting 1998, pupping 1999, and molting 1999, respectively. A total of 5,288 photographs were taken of 1,691 "temporary" seals (includes new marks and resights; Figure 2). Of these seals, 148 were photographed from close range during live-animal capture trips at Tugidak Island and in Prince William Sound. The remaining 1,543 seals were photographed using the camera system described in the methods and included: 48.1% seals of known sex (50.7% male); 67.4% adults, 14.6% subadults, 8.4% yearlings and 9.6% pups; 81.7% light color phase, 9.5% intermediate color phase and 8.8% dark color phase seals. Of the 1,691 temporary seals, 1,668 (98.6%) had photos taken of the right or left view of the head, of which, 1,403 temporary seals were fingerprinted (84.1%). Fingerprint rates were low at the beginning of the study ranging from 18 - 41% for pupping season 1998 photos but improved to 88 - 95% by the molting season 1999 (Figure 2). Increased effort during the molting season 1999 resulted in over 55% of the data occurring in this period.

Performance of matching technique

Matching software performed well when using side views and relatively poor when using front views. Photograph matching error rates were 6.2% for side views and 34.6% for front views (Figure 3). Efficiency (or the proportion of non-matching photographs that did not have to be checked visually) using this critical level was high for both views at > 99% for front and side views. Lowering the critical value would not significantly improve photograph matching error rate for side views, because most missed matches were caused by poor photograph or pelage quality producing very low scores (Figure 3a). For example, choosing a critical value of 1.0 would only decrease error rate to 5.4% and efficiency to 96%, for side views.

The error rate of 5-6% applied to photographs not screened for quality. The *photograph* matching error rate will be higher than the *animal* matching error rate, which depends not only on photograph matching errors but also on how many photographs are available for matching. Generally, the two best photographs for a seal are fingerprinted, such that several fingerprints are available for comparison with many fingerprints available in the database (if the animal has been marked before). The animal matching error rate, rather than photograph matching error rate, is most important to understanding how missed matches will affect capture histories of seals. Matching error rates for grey seal photographs have been tested extensively. While photograph matching error rates were similar for grey seal and harbor seal photographs, the *animal* matching rate for grey seal photographs was only 2-3% when using many photographs of "high-quality" per occasion. We expect harbor seal photographs will yield similar low (2-3%) animal matching error rates when using several, high-quality photographs per occasion; though future tests will be conducted to confirm this.

Preliminary estimation of resighting rates

<u>Between-year resighting rates</u>

Because of poor matching rates for front views, we used data from side views to examine resighting rates. After matching photographs, the 1,403 temporary seal numbers resulted in 1,200 new permanent seal numbers (new marks) and 203 resights. Of these resights 77.1% (155) were on different days (resights of interest); and 22.9% were seals mistakenly photographed more than once on the same day and assigned different temporary animal numbers. Of the 155 resights that occurred on different days, 65.2% (101) were of seals first marked and resighted during molting 1999 (Table 1). Resights of seals first marked in 1998 (42; 27.1% of resights) were used to estimate annual resighting rates. Reduced effort in the 1999 pupping season resulted in low sample size and poor resighting rates with rates of only 0.01-0.03 for side views when data from all seals, regardless of quality, were considered (Table 1). Resighting rate increased to 26% for the right side view when the larger sample size from molting season 1999 was considered. Higher resighting rates for the right side view than the left side view resulted from increased effort at photographing right sides once we noticed a slightly higher tendency for seals to show their right side. In the 1999 data, 40.6% of fingerprints were classified as "high-quality". By assuming all matches were from high-quality fingerprints, a reduction in the total new marks by 59.4% resulted in an upper estimate for resighting rate of 0.65-0.70 for seals with high-quality right-side-view photographs (Table 1). We expect resighting rates of 0.26 to 0.65 will be sufficient for estimation of annual survival probabilities.

<u>Within-season resighting rates</u>

Data from high-quality photographs included 265 seals marked and 28 within-season resights for the molting season 1999. Estimates of population size, marked population size, and number of births were very poor using these data and the program JOLLY, with CVs (SE/Estimate) from 46% to over 100% when using the full Jolly-Seber model (Model A). A reduced parameter model (Model D, survival and resighting rate constant over time) was chosen as a better model than Model A (Likelihood Ratio Test, $X^2_5 = 7.287$, $p = 0.20$), and the intermediate model (Model B, constant-time survival, time-varying resighting rate) failed to converge. Goodness of fit tests indicated both models A and D fit the data (both $p > 0.33$) but most cells had insufficient data to perform the tests (degrees of freedom = 2 and 7 for models A and D, respectfully). The constant resighting rate estimate from Model D was quite low at 0.081 (SE = 0.021). All estimates of within-season resighting probabilities from Model A were imprecise with CVs > 50%. CVs for population size, marked population size and births were improved but still very large (26 to 80%) using model D and therefore useful estimates of population size were not possible.

We further modeled the data from high-quality photographs using MARK to examine within-season resighting probabilities because MARK allowed differing time intervals for survival and more powerful modeling capabilities. However, MARK does not allow population size or number of births to be estimated, though a link to the program POPAN, which does compute estimates of these parameters, is currently being developed. Average time intervals between occasions were input into the model to produce a per-day retention rate of seals (inverse of per-day emigration rate). This lent reality to the model though the "survival" parameter was not of interest in this case. Four models were fit to the data. Resighting rate estimates were taken from the model with constant survival per day and time-varying resighting rate because this model was over twice as well supported by the data as the next best model (AICc Weight = 0.613/0.254; Table 2). Comparison of deviance using a bootstrap goodness-of-fit test indicated this model fit the data (p = 0.82). Resighting rates varied significantly among occasions from 0.011 to 0.097 (Table 3). These preliminary analyses indicated sample sizes of high-quality photographs were too small and within-season resighting rates too low to estimate population size, reproductive rate and associated parameters using photo-id and this level of effort. Unfortunately, maximum effort was put towards collecting these data in the molting season 1999, such that it will not be possible to significantly increase our effort at photographing heads of seals beyond this level.

SUMMARY AND FUTURE WORK

The technique of Hiby and Lovell (1990) provided an objective method for matching photographs and identifying individual harbor seals with low probability of false negatives when using side views. Resighting rates may be adequate for estimation of annual parameter estimates but larger sample sizes will be needed for within-season estimates of population size. With high effort (seals photographed on 19 out of 34 days), within-season resighting rates ranged from 0.01 to 0.10, whereas between year resighting rate was 0.26, and potentially as high as 0.71 for well-marked subadult and adult seals. Several enhancements to the project are now being pursued: (1) the use of digital photography to obtain larger sample sizes and reduce photograph processing time and costs; (2) the creation of a computer model of the ventrum side of the body which is easier to photograph, removes the issue of "viewpoint", and allows all seals to be sexed and therefore provides better demographic data; and (3) development of objective techniques for categorizing photograph and pelage pattern quality. Sample size and within-season resighting rate is most limited by the rate of acquiring photographs in the field. Both digital photography and the ventrum view may allow a faster rate of photography, and therefore larger sample sizes, by (1) eliminating the need to handle rolls of film in the field, and (2) photographing stationary seals whose sex is more readily visible (as with the ventrum view) rather than seals that are often moving or obscuring their sex (as in the head view).

After several more years of data collection, data will be analyzed using mark-recapture models to estimate annual survival and reproductive probabilities, and potentially population size, pup survival and temporary and permanent emigration probabilities. We are particularly interested in juvenile survival and in estimating age-specific demographic parameters. We will continue to photograph over a series of years known-age captive seals at aquariums and seals tagged as pups on Tugidak to further test for age-related changes in pelage patterns and to determine if pups can be followed reliably to adulthood using this method.

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Table 1. Number of harbor seals that were newly marked (photographed) and resighted during the 1998 and 1999 pupping and molting seasons at Tugidak Island. Numbers not in parentheses are for all age-classes combined; numbers in parentheses are for adults and subadults only.

Season	View	New Marks[a]	Total[b] Resights *diff days*	Resights (First Marked)[c] *98 Pup*	*98 Molt*	*99 Pup*	*99 Molt*	All Seals[d] Total Marked[f]	Annual Return Rate[g]	Annual Resighting Rate[h]	Well-Marked Seals[e] Total Marked[f]	Annual Return Rate[g]	Annual Resighting Rate[h]
98 Pup	Right	61 (42)	0	0	-	-	-	61 (42)	-	-	25 (17)	-	-
	Left	32 (23)	0	0	-	-	-	32 (23)	-	-	13 (9)	-	-
98 Molt	Right	93 (90)	4 (4)	1 (1)	3 (3)	-	-	154 (132)	-	-	63 (54)	-	-
	Left	53 (47)	2 (2)	1 (1)	1 (1)	-	-	85 (70)	-	-	35 (28)	-	-
99 Pup	Right	74 (31)	1 (1)	1 (1)	0	0	-	228 (163)	0.01 (0.01)	0.01 (0.01)	93 (66)	0.02 (0.02)	0.03 (0.03)
	Left	73 (38)	2 (2)	1 (1)	1 (1)	0	-	158 (108)	0.02 (0.03)	0.03 (0.04)	64 (44)	0.06 (0.07)	0.08 (0.09)
99 Molt	Right	399 (355)	107 (100)	10 (8)	23 (23)	5 (5)	69 (64)	627 (518)	0.21 (0.23)	0.26 (0.29)	255 (210)	0.52 (0.57)	0.65 (0.71)
	Left	333 (281)	39 (38)	0	6 (6)	1 (1)	32 (31)	491 (389)	0.07 (0.09)	0.09 (0.11)	199 (158)	0.17 (0.21)	0.21 (0.26)

[a] New Marks: Number of seals fingerprinted for the first time

[b] Total Resights, diff days: Total number of resights including only resights made on different days (resights resulting from assigning more than one temporary seal number to the same seal in the same day are not included)

[c] Resights (First Marked): Indicates when resighted seals were first marked (Resights 98Pup + 98Molt + 99Pup + 99Molt = Total Resights)

[d] All Seals: Includes all seals fingerprinted regardless of photograph or pelage pattern quality

[e] Well-Marked Seals: Includes only seals with high-quality fingerprints by adjusting the total marked by the estimated proportion of seals fingerprinted that had high-quality photos and pelage patterns in the 1999 data (determined by subjective and objective methods to be 40.6%).

[f] Total Marked: Total number of seals fingerprinted to date

[g] Return rate: Total resights of seals first marked in 1998/ total seals marked by the end of 1998

[h] Resighting rate: Return rate/survival rate (assuming survival is 0.80 and emigration rate is 0.0; or the combined probability of surviving and remaining at Tugidak is 0.80)

Table 2. Results of model selection using MARK and data from photographs categorized as "high-quality". AICc = Akaike's Information Criterion corrected for effective sample size; Delta AICc = difference in AIC between successive models; AICc Weight = normalized AIC weights providing an index of relative likelihood for each model; Num Par = number of parameters in model; Deviance = Deviance of model. Model notation: ϕ = "survival" (or the inverse of emigration probability in this case), p = within-season probability of resighting, (t) = time-specific parameters, ( ) = parameters constant across time. Survival rates were adjusted in the model to account for different average number of days between capture occasions, yielding per-day survival rate.

Model	AICc	Delta AICc	AICc Weight	Num. Par	Deviance
ϕ ( ) p (t)	239.327	0.000	0.613	6	12.150
ϕ ( ) p ( )	243.214	3.887	0.088	2	24.308
ϕ (t) p (t)	244.521	5.194	0.046	9	10.974

Table 3. Estimates of within-season resighting rates from the best model from MARK [model ϕ ( ), p (t)]. SE = standard error, p = probability of resighting per occasion (2 – 6), and ϕ = "survival" probability per day (inverse of per-day emigration rate).

Parameter	Estimate	SE	95% Confidence Interval
p (2)	0.080	0.046	0.025 – 0.229
p (3)	0.097	0.038	0.044 – 0.201
p (4)	0.046	0.022	0.017 – 0.116
p (5)	0.042	0.020	0.017 – 0.102
p (6)	0.011	0.009	0.002 – 0.050
ϕ ( )	0.978	0.032	0.709 – 0.999

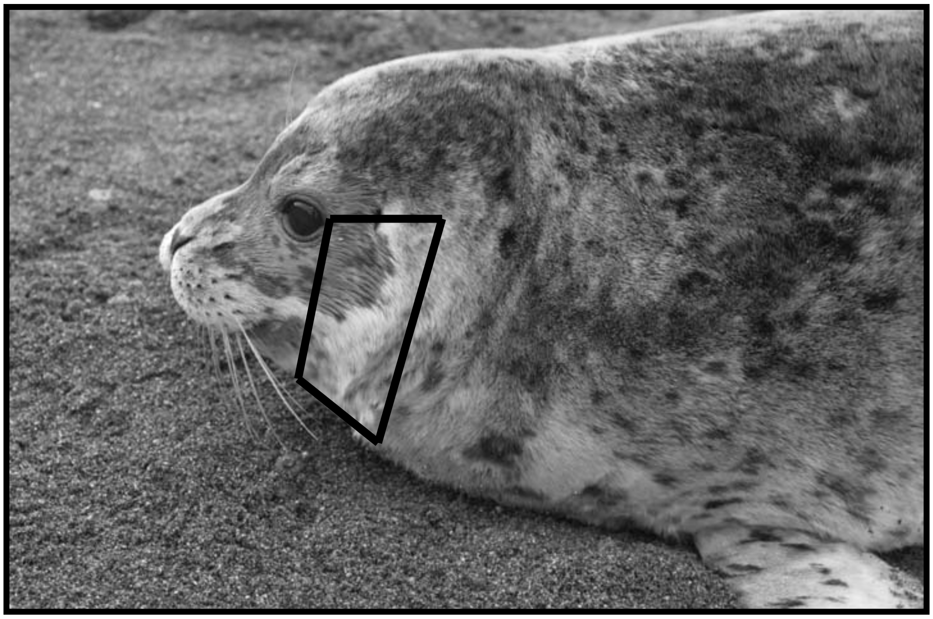

Figure 1a. Fingerprint region on the side of the head

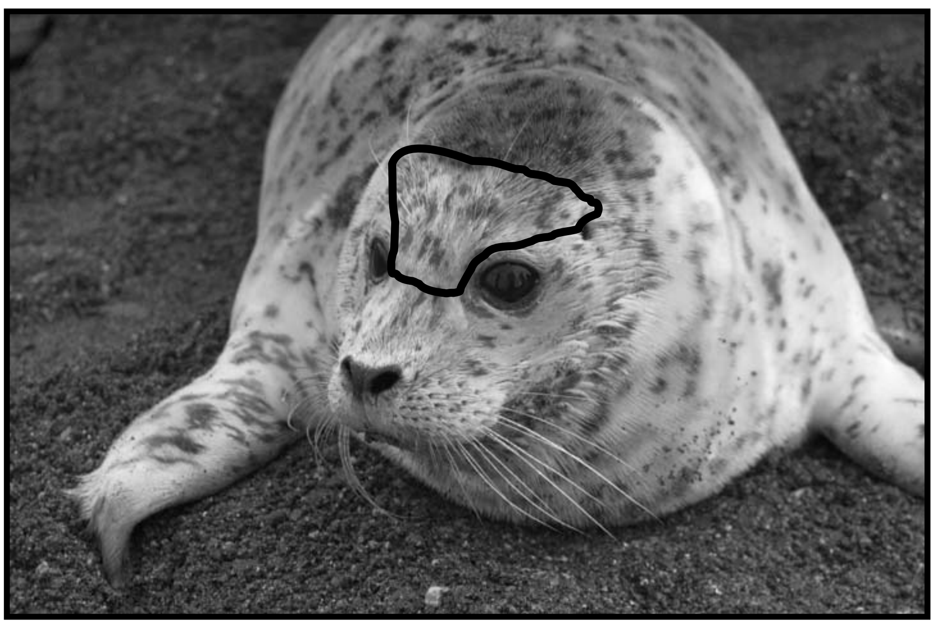

Figure 1b. Fingerprint region on the front of the head

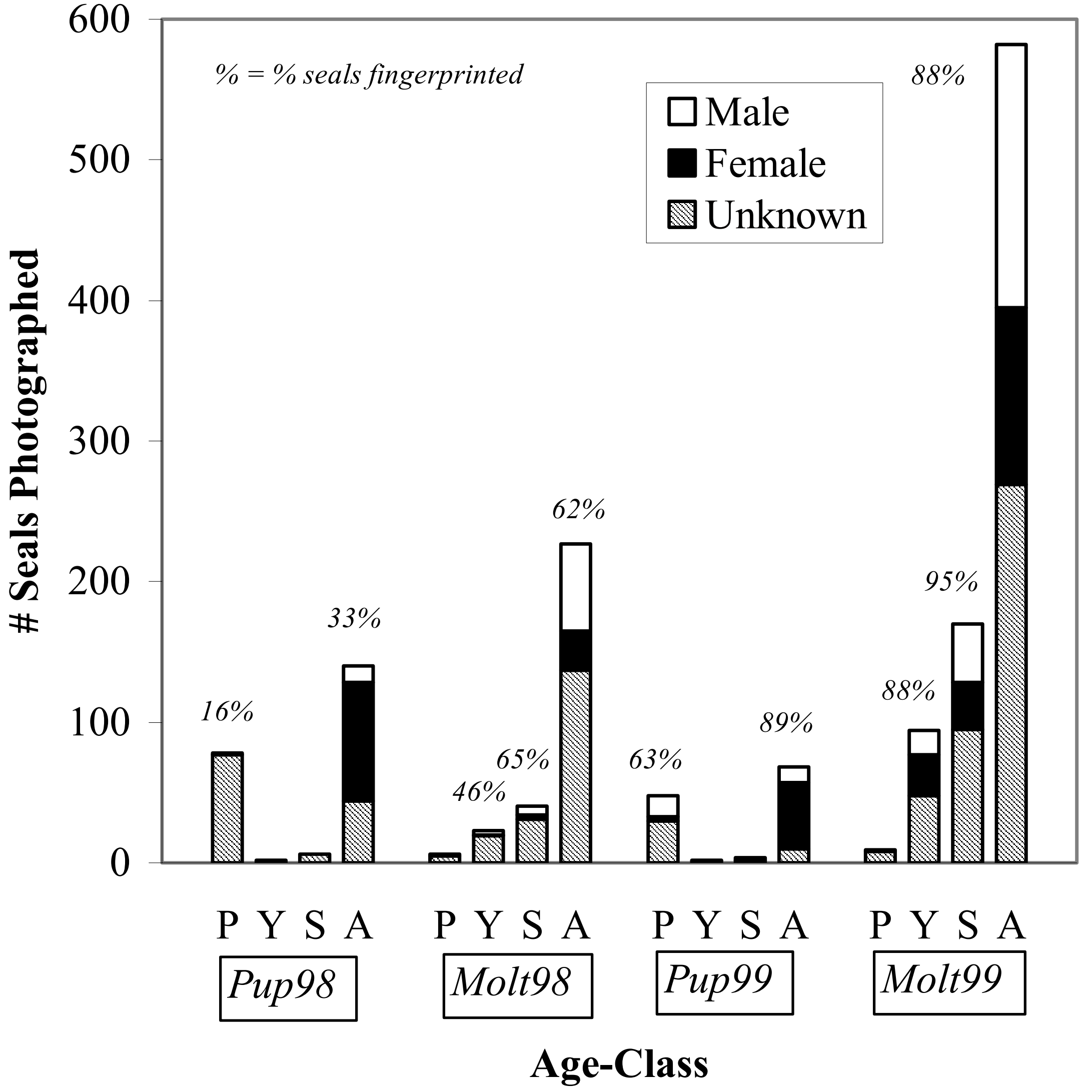

Figure 2. Sample sizes of harbor seals photographed on Tugidak Island, Alaska, during the pupping and molting season 1998-1999. Age-classes denoted as Pup (P), Yearling (Y), Subadult (S), and Adult (A). % Seals fingerprinted = % of seals photographed that had the pelage pattern in at least one fingerprint region analyzed and were entered into the fingerprint database.

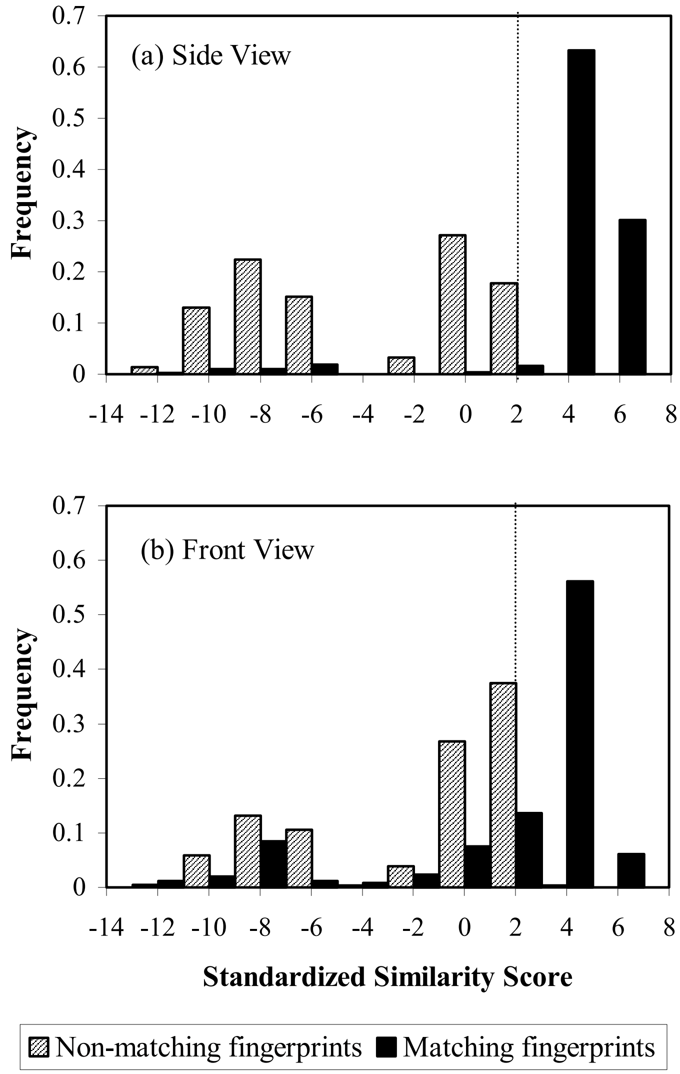

Figure 3. Performance of side (a) and front (b) fingerprint matching software. Matching fingerprints = scores from different photos of seals with the same permanent animal number; Non-matching fingerprints = scores from photos of seals with different permanent animal numbers. Similarity scores were defined as the correlation between the elements in the numerical description (identifier array, see text) of the two fingerprints. This score was standardized to be expressed as the number of standard deviations the score lied above the mean score that fingerprint obtained from comparisons with all other fingerprints in the database. Scores above 1.9 (dashed line) were considered matches; matches with scores below 1.9 will be missed by the system. Side fingerprints performed well with only 6.2% of matches missed; while front fingerprints had a higher failure rate of 34.6%. Matches with scores above 1.9 for non-matching fingerprints would be eliminated by visual inspection producing a 0% chance for false positives.